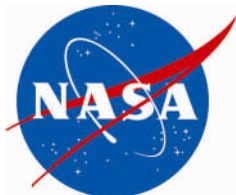


NASA/TM-2008-215100
NESC-RP-06-115/06-028-E



International Space Station (ISS) S-Band Corona Discharge Anomaly Consultation

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January 2008

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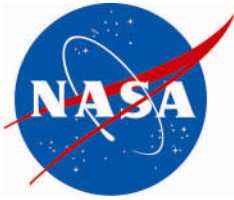
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January 2008

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December 14, 2006


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Volume I: Technical Consultation Report

1.0 Authorization and Notification


The request to conduct a consultation on the ISS S-Band Corona Discharge Anomaly was submitted to the National Aeronautics and Space Administration (NASA) Engineering and Safety Center (NESC) on May 8, 2006. The consultation was approved on May 9, 2006, in an out-of-board action by the NESC Director.

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3.0 Team Members, Ex Officio Members, and Consultants

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4.0 Executive Summary

The Assembly and Contingency Radio Frequency Group (ACRFG) onboard the International Space Station (ISS) is used for command and control communications and transmits (45 dBm or 32 watts) and receives at S-band. This system is nominally pressurized with gaseous helium (He) and nitrogen (N₂) at 8 pounds per square inch absolute (psia).


One of the ISS ACRFGs (S/N 002) leaked during operation to a pressure of 1 psia. An increased reflected radio frequency (RF) transmit power signature in this unit was observed on April 13, 2006. This ACRFG is a backup system that is normally in not in a powered state. The primary ACRFG (S/N 003) has no detectable pressure decay and has been operating within specification limits.

MacDonald, Dettwiler and Associates Ltd. (MDA) was engaged to analyze the operational characteristics of this unit in an effort to determine if the anomalous behavior was a result of a corona event. Based on this analysis, MDA did not recommend continued use of this ACRFG. However, both the primary and backup ACRFGs are required to be active for all Extravehicular Activities (EVAs), dockings, and undockings. In addition, for all EVAs resulting in an unmanned ISS, flight rules require both ACRFGs to be operational for command and control of the ISS in the event of a problem.

The planned EVA scheduled for June 1, 2006, required activation of both ACRFGs. The NESC was requested to provide expert support in the area of high-voltage corona and multipactoring in an S-Band RF system and to assess the probability of corona occurring in the ACRFG during the planned EVA. The NESC team concurred with the use of S/N 002 during the EVA with the stipulation that failure of the unit is possible and should not produce a failure outside the unit.

Following the successful spacewalk, the NESC team was requested to review the test plan and results of an engineering corona test on a bandpass filter assembly believed to be susceptible to corona at the reduced pressures.


Following these reviews, the NESC recommended minimal continued use of S/N 002 ACRFG until a replacement unit can be installed. Following replacement, S/N 002 will be subjected to destructive failure analysis in an effort to determine the proximate and root cause(s) of the anomalous behavior.

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5.0 Consultation Plan

A team with relevant expertise was formed to review and provide expert consultation regarding high voltage corona and multipactoring in an S-Band radio (RF) system on the ISS.

The team's objectives were to provide expert support in the area of high-voltage corona and multipactoring in an S-Band RF system, read and evaluated reports from the S-band RF Group Orbital Replacement Unit (ORU) vendor, MDA, on the probability of corona occurring in the ACRFG, and review a test plan and results of an engineering corona test on a bandpass filter assembly believed to be susceptible to corona at the reduced pressures.

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6.0 Description of the Problem and Proposed Solutions

6.1 Description of the Problem

On April 13, 2006, there was a reflected RF power anomaly observed after four minutes nominal operation within the ACRFG (refer to Figure 6.1-1). This was in the “String 1 RFG” unit on S1 (S/N 002) as shown on the ISS in Figure 6.1-2. The “String 2 RFG” unit (S/N 003) on P6 is the primary unit. The spare unit (S/N 001) is stowed on Z1. Corona was examined as a possible root cause of the anomaly. Section 3.5 of the MDA ACRFG Reflected RF Power Anomaly Report (ref. 1) determined the necessary voltages to produce corona, at various pressures, in the narrowest electrode gaps in the coaxial cavity 5-pole diplexer and 3-pole bandpass filter (see Figure 6.1-3) assemblies. The results of the MDA analysis suggest the conditions present in the Bandpass Filter and Diplexer at 1 psia may have been favorable for the corona.



Figure 6.1-1. S-Band Assembly Contingency RF Group (ref. 5)



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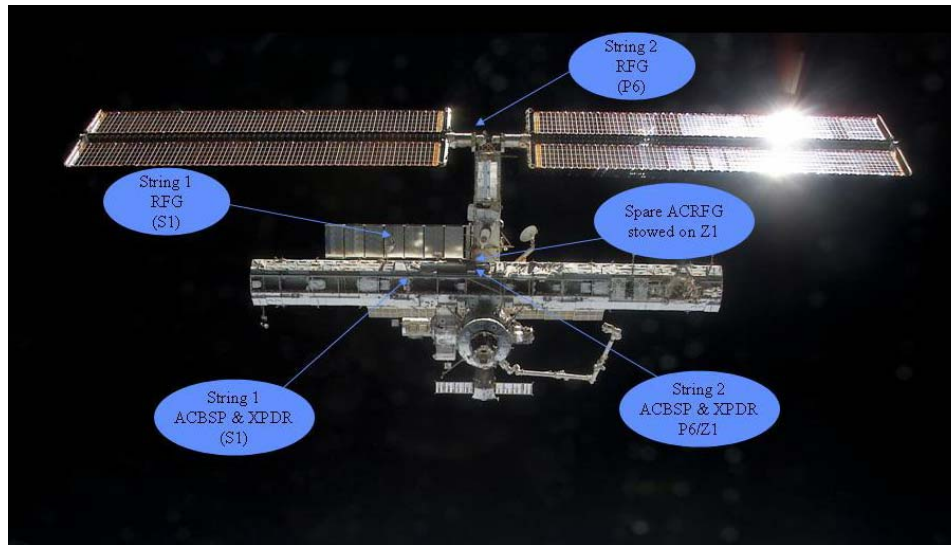



Figure 6.1-2. ISS S-Band Installation Sites



Figure 6.1-3. Bandpass Filter Assembly (ref. 5)

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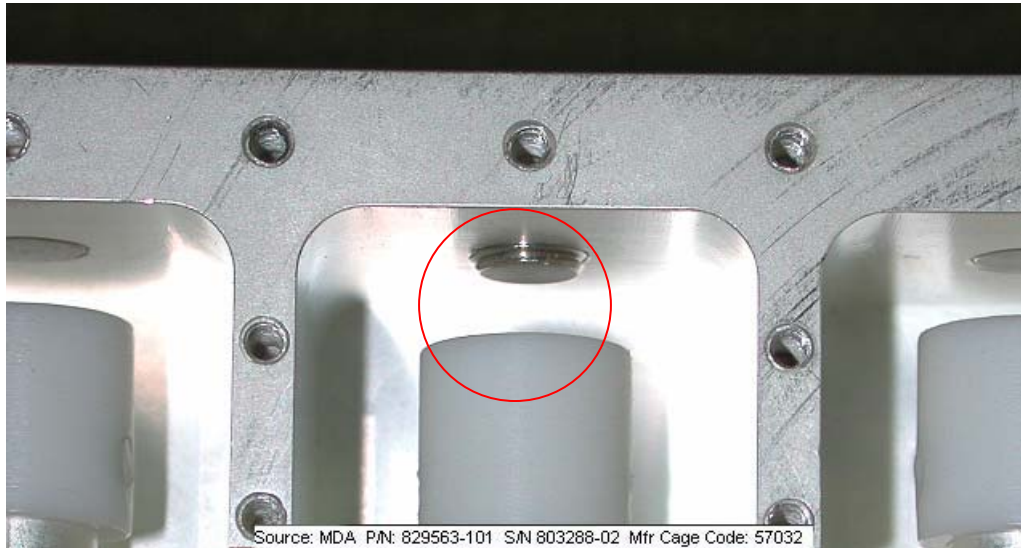



Figure 6.1-4. Bandpass Filter Tuning Screw and Gap (ref. 5)

However, corona was judged unlikely in the initial MDA report because of the observed on-orbit condition of four minutes of normal operation followed by degraded service. The end of Section 3.5 (ref. 1) states: "Corona events tend to be a violent occurrence and with permanent damage. Continued operation would not be sustained." For these reasons, a solder joint at the input to the bandpass filter was initially identified by MDA as the most likely proximate cause of the on-orbit ACRFG anomaly.

6.2 Proposed Solution

The NESC team concurred with the ISS Program's proposed use of the ACRFG for the June 6, 2006 EVA followed by storage and replacement if it can be accepted that loss of the unit could occur and it can be confirmed that failure would not propagate to adjacent components. The NESC team recommended conducting a 1-psia corona test on the non-flight unit, and doing so if possible before the on-board unit is turned on. The test may prove that the unit would run better than the analysis indicated and also determine how the unit will perform with reduced pressure.

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7.0 Data Analysis

The major tasks completed during the consultation included the following:

- Reviewed and participated in discussion on MDA RF corona analysis.
- Reviewed on-orbit pressure decay data.
- Reviewed test plan for corona test of engineering unit.
- Performed analysis of probability of corona at low pressures.
- Reviewed results of the engineering tests of a Bandpass Filter assembly.

The results of each of these tasks will be discussed in the following sections.


7.1 Review of MDA Corona Analysis and Pressure Decay Data

A teleconference was conducted with the NESC team members, ISS personnel, and contractor, MDA, on May 9, 2006, to discuss the MDA's draft ACRFG Reflected RF Power Anomaly report dated May 5, 2006 (ref. 1). The preliminary comments summarized below were forwarded to the ISS Program on May 10, 11, and 17, 2006.

The MDA's analysis showed probable formation of a coronal discharge within the transmitter filter, and possible formation at other locations within the unit, at a pressure of 1 psia. MDA's computations are intrinsically uncertain as the actual coronal discharge is sensitive to cavity features that were ignored (or not well known) in the utilized model. Therefore, it is not appropriate to use the predicted negative margin as conclusive proof that there was corona present. However, a review of the analysis, other assumptions, and boundary conditions suggest it is reasonable to suppose that there was a corona event.

Regarding the MDA analysis, the 1970 Jet Propulsion Laboratory (JPL) document, Technical Report 32-1500 "Final Report on RF Voltage Breakdown in Coaxial Transmission Lines" (ref. 6) used to determine the corona calculations also explains the complexity of the variables (pressure, distance, and frequency) that are used. This computation is far more involved than a direct current (DC) or low frequency application of the Paschen curve. The accuracy of translating the JPL report's coaxial configuration test data to a different geometry is not known. The report also states a more pronounced effect on breakdown at high frequencies due to conductor shape variations.

Section 3.5 of the MDA report determined the necessary voltages to produce corona, at various pressures, in the narrowest electrode gaps present in the subassemblies. As shown, the conditions present in the three pole Band Pass Filter and Diplexer at 1 psia may have been

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favorable for corona. However, corona as a cause was judged unlikely because of the observed on-orbit conditions of four minutes normal operation and then degraded operation. The end of Section 3.5 states “Corona tends to be a violent occurrence and with permanent damage. Continued operation would not be sustained.”

The NESC team supported the engineering corona test that was proposed during the teleconference. However, there were some concerns expressed on configurational differences between the ACRFGs in ground testing and the flight units that could affect the test results.

A low pressure 1 psia test is needed to establish two critical points:

a. Verify the expected destructive characteristic of a corona suggested in Section 3.5 of the MDA report.

It has been the experience of the NESC team high voltage expert that in some cases corona is not necessarily violent, and a prediction of permanent damage is difficult to substantiate. While the breakdown voltage has been estimated, breakdown energy had not been determined especially in reference to the power that can be delivered. While it is doubtful that the corona energy could be supported with continued operation, perhaps a sustained low power level corona may have existed.


b. Verify derived voltage breakdown estimates.

Section 3.5 states the use of R. Woo’s Technical Report (ref. 6) in determining the breakdown voltages at various pressures for the 2.25 giga hertz (GHz) operation and mentions the uncertainty introduced by sharp edges producing field enhancements. Even though the derived corona inception voltages are viewed as “best case,” perhaps the actual breakdown voltages are higher. Although not likely, this test could give stronger evidence that corona did not occur.

The 1970 Woo report (ref. 6) uses some measured data and some derived data in its Figure 21, RF Voltage Breakdown in Uniform Fields in Air, and with the difficulty of extrapolating from the plot, the accuracy may not be adequate. Perhaps more recent reports may provide supporting data. As stated, the introduction of non-uniform fields in the actual hardware will alter the breakdown voltage, probably downward. However, the affect on non-uniform fields in RF voltage breakdown are not always predicable.

The NESC team suggested that the 1 psia corona test should be performed on the non-flight unit before the on-board unit is turned on. This was not intended to imply a mission constraint, since it may be argued that box failure of the ACRFT (S/N 002) would not be adverse to safety. This opinion was that a test would provide more objective evidence than an analysis in determining how the unit will perform with reduced pressure.

The MDA report had concluded that a solder joint failure at the input of the bandpass filter was the most likely proximate cause of the on-orbit anomaly. The NESC Team noted that it is

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possible that corona inside the filter cavity could erode (or more likely melt open) the solder connection attaching the injection loop's end to the case-wall, leading to a separation and result in observed signal loss. If the solder melted, or even reached the softening temperature, then the residual stresses in the loop (shown in Figure 3.2-2, page 16 of the MDA report) could allow separation. This hypothetical detachment would also drop the voltage level in the cavity below the value needed to sustain the corona, at least for the present pressure. If this solder connection separation has happened, then there can be no further corona until the pressure decreases enough to move the system far enough along the Paschen curve so that the plasma threshold drops to the now-available voltage level. The predicted time for this change in plasma threshold could be approximated from the measured leak rate and the Paschen curve for N₂.


The details of the separation between the loop's end and the case could be temperature-dependent, and this could perhaps cause the now-observed temperature dependence of the signal loss. This seems possible, but is certainly not established with any certainty. Testing with a ground unit may be useful in probing this candidate explanation.

The ACRFG S/N 002 has been recently operated for durations extending to 24 hours and shown essentially stable operation, aside from initial "warm up" transients lasting for times on the order of seconds to tens of minutes. These characteristics are consistent with "no corona" performance. However, it is expected the potential for corona will increase when the internal pressure degrades further.

Hence, operation of ACRFG S/N 002 was a reasonable use of assets for the EVA planned for June 6, 2006. It was prudent to document that no coronal-induced damage can "escape" the transmitter to cause harm or mis-function of adjacent equipment. It is likely that the diplexer will protect the receiver so even if the transmitter fails, the receiver may remain viable. This may not matter since if the transmitter fails completely, the redundant unit (S/N 001) will most likely be used.

There is a possible concern related to the isolator/dummy load in the transmitter solid state power amplifier. Can heat or some other failure in the dummy load cause a failure beyond this subsystem? If a fuse blows, will only this subsystem be affected? It also must be recognized that as the ACRFG S/N 002 this transmitter is now operating "off design," it may degrade further at any time.

The NESC team also suggested evaluating the on-orbit performance data more thoroughly with additional trend information (temperature, pressure, etc.). The NESC team observed that the choice of N₂ plus He may not be optimal for RF applications. It was suggested that a superior dielectric gas such as N₂ plus sulfur hexafluoride (SF₆) should be considered. SF₆ is a very electro-negative molecule that does not give up electrons readily which suppresses corona.

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Further, the use of 8 psia as the base internal pressure level adds risk for two reasons. First, a leak on the ground is difficult to assess since the pressure differential is somewhat less than in a vacuum (6.7 psia versus 8.0 psia), and the gas that would leak in on the ground (air) is different than the gas that would leak out (N₂ plus He) in space. Second, the pressure vessel goes from being compressed on the ground to being expanded in space. Therefore, a leak may not show up on the ground that may occur in space.

One other item of interest to the NESC team was the leak performance on the other RF systems (and the spare if it has been stored in vacuum). Has it also leaked down or is it holding pressure correctly? This has implications for both better understanding the problem as well as developing an optimal replacement strategy.

The on-orbit symptoms do not indicate corona had occurred to produce the observed anomalous performance. Although the development of corona at some point cannot be precluded due to continued internal pressure decay.

It would be beneficial to evaluate an actual solder joint. It may be possible that thermal changes affecting a solder joint could produce the anomaly alone. However, there is no present analysis to show what the thermal range is.

The NESC team reviewed pressure decay data provided by the ISS Program (ref. 3). Concern was expressed that the real Paschen domain will be entered in the next year or so. Therefore, even if acceptable operation was achieved for the planned June 6 EVA, it will be important to replace this unit with an acceptable ACRFG as soon as practical.

The NESC team was asked to review an additional report “ACRFG EPC Worst Case Voltage Summary Rev E.” On page 21, the report states: “It was determined that all printed circuit boards (PCBs) and terminals are adequately conformally coated, including all transformers.” The NESC team noted that conformal coating can block a current flow (by introducing a high resistance), but it will not block an electric field. It can affect an electric field through its dielectric constant, but most conformal coatings are thin and so this effect is often ignorable. An electric field within a cavity induces the ionization of gas, and thereby creates corona, regardless of the presence of any conformal coating.

7.2 Analysis of the Probability of Corona Occurrence at Reduced Pressures

On May 17, 2006, the NESC team was requested to assist with calculations of probability of corona events as pressure decreases below the current level of 1 psia. The results of these analyses were provided to the ISS Program on May 23, 2006 and are summarized below.

The charts in Figure 7.2-1 show the RF breakdown voltages for a range of pressures in an air environment (refs. 5 and 6). For the purposes of this analysis, N₂ and air are considered



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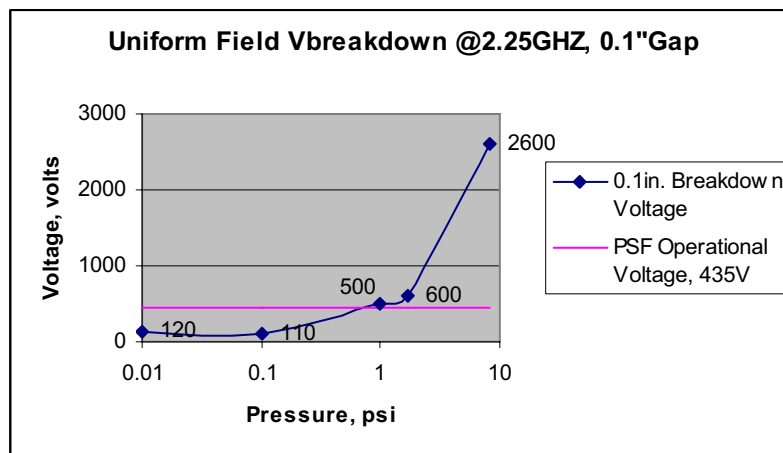
equivalent. As discussed, the actual levels need to be determined by test, as the data is retrieved from the ideal case of uniform fields.

However, it can be seen that the worst case range is between 0.01 and 1 psia and the inception level is so low that corona is likely.

As an engineering judgment, it would be reasonable to assign the following probabilities:

1. At pressures between 0.001 psia and 1 psia, corona is almost certain (>90 percent) for the gap sizes within these assemblies (>90 percent).
2. At pressures of greater than 2 psia, corona at any gap size is unlikely (<10 percent).
3. Between 0.1 and 1 psia, the margin between the operating voltage and corona inception level is essentially non-existent, and the likelihood of corona should be moderate (~70 percent).
4. Below approximately 0.001 psia, multipactor breakdown dominates over ionization breakdown. Corona does not occur in hard vacuum (e.g. <0.00001 psia). However, multipactor breakdown is still possible for small gaps (0.1 inch) in this pressure region, so a breakdown probability of 50 percent would be appropriate.

In the 1 to 2 psia region, the probability of corona is undefined. This is the “knee” of the Paschen curve where the breakdown voltage characteristic changes greatly with small changes in pressure.





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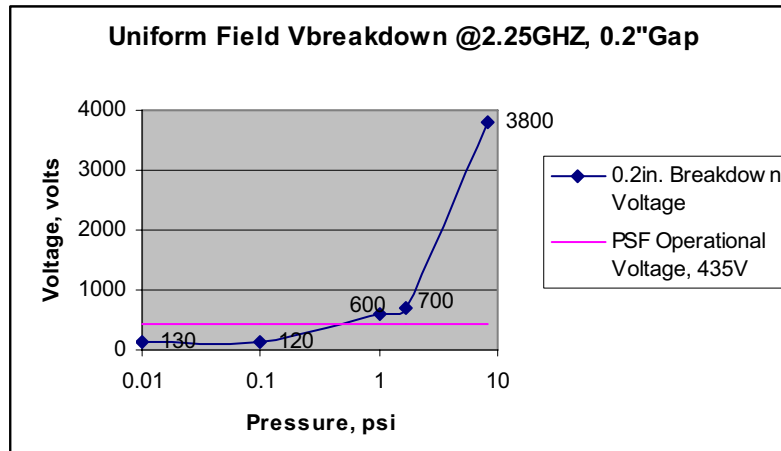


Figure 7.2-1. Breakdown Voltage versus Pressure for Various Gaps (in air) from Woo Curves (ref. 6)


7.3 Engineering Bandpass Filter Corona Test Results Review

The ISS Program requested that MDA perform an engineering corona test of a bandpass filter assembly, per the May 9, 2006, teleconference discussions. The ISS Program requested that the NESC team review and comment on the corona test plan (ref. 2) and report. The test report was provided to the NESC team, and written comments were solicited (ref. 4). A teleconference to discuss these was held with NESC ISS Program and Boeing personnel on November 28, 2006. Written inputs were provided on November 12 and 14, 2006, to the ISS Program. These inputs are summarized as follows.

The NESC team concluded that in the test bandpass filter a corona event was observed repeatedly at 0.3 psia which could explain the on-orbit observations. The NESC team observed that the report is well written and shows clear distinction between corona and multipactoring with excellent use of pictures and graphs. An interesting result of the test was that the filter properties were essentially unchanged after the testing, even though there was visible evidence of the corona. Permanent damage did not occur as a result of approximately 12 minutes of corona conditions during the testing. This may possible be due to the limited duration allowed for the corona. Although not tested, multipactoring may also be a threat at very low pressures (less than 2×10^{-5} psia).


However, the NESC team noted that a key missing item was a test to failure in order to understand how many hours of operation (as the system is operated) can be realistically expected prior to complete failure.

As a note on N_2 plus He, the addition of He dramatically reduces the breakdown voltage at low pressures. However, the He will have leaked out so the N_2 operation is probably realistic.

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The test results were quite good, especially to show good correlation between predicted and measured conditions of frequency, pressure, and power levels. It was not clear to the NESC team whether the report's conclusion claims corona the likely cause or still just a possible cause of the observed performance anomaly.

During the November 28, 2006, teleconference, the NESC team concluded that the results of testing substantially increased the relative likelihood of corona as being the cause of the on-orbit anomaly (estimated as from a level of 1 or 2 to 5 on a scale of 10).

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8.0 Findings, Recommendations, and Observations

8.1 Findings


- F-1. Corona inception is a real threat at reduced pressure of approximately 1 psia.
- F-2. An engineering unit test to assess corona effects provided valuable technical insight. Permanent damage did not occur as a result of approximately 12 minutes of corona conditions during the testing.
- F-3. The team concurred with use of the ACRFG (S/N 002) for the June 6, 2006, EVA as long as it can be accepted that loss of the unit could occur, and it can be confirmed that failure would not propagate outside the unit.
- F-4. The team concurred with the engineering bandpass filter test report conclusion that the results show corona may be one of the possible causes for the ACRFG (S/N 002) on-orbit behavior.

8.2 Observations

- O-1. Although not tested, multipactoring may also be a threat at very lower pressures (less than 2×10^{-5} psia).
- O-2. It was noted that although this RF system is dependent on maintaining pressurization for proper operation and pressure, leakage is a credible failure mode. Instrumentation used to measure internal pressure did not have sufficient resolution and accuracy to make accurate measurements in the low pressure regime where multipactoring or corona can occur.

8.3 Recommendations

- R-1. Perform a failure analysis on the returned anomalous ACRFG (S/N 002) to determine the proximate and root cause(s) of the on-orbit malfunction. (F-4, O-1)
- R-2. With the continued loss of pressure, avoid further operation of the anomalous ACRFG (S/N 002) unit. (F-4, O-1)

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9.0 Alternate Viewpoints


There were no alternate viewpoints expressed during this consultation.

10.0 Other Deliverables

There were no other deliverables for this consultation.

11.0 Lessons Learned

LL-1. RF systems that are dependent on maintaining pressurization for proper operation should consider the addition of instrumentation to measure internal pressure with sufficient resolution and accuracy to make trustworthy measurements in the low pressure regime where multipactoring or corona can occur.

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12.0 Definition of Terms

Corona	Corona is caused by electrons torn out of atoms of a gas by a strong electric field causing a current to flow in the gas.
Corrective Actions	Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem.
Finding	A conclusion based on facts established during the assessment/inspection by the investigating authority.
Lessons Learned	Knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or limits the potential for failures and mishaps, or reinforces a positive result.
Multipactoring	Resonant effect caused by electrons accelerating due to an electric field in a vacuum and colliding with a metal surface with enough energy to cause the emission of secondary electrons.
Observation	A factor, event, or circumstance identified during the assessment/inspection that did not contribute to the problem, but if left uncorrected has the potential to cause a mishap, injury, or increase the severity should a mishap occur.
Problem	The subject of the technical assessment/inspection.
Requirement	An action developed by the assessment/inspection team to correct the cause or a deficiency identified during the investigation. The requirements will be used in the preparation of the corrective action plan.
Root Cause	Along a chain of events leading to a mishap or close call, the first causal action or failure to act that could have been controlled systemically either by policy/practice/procedure or individual adherence to policy/practice/procedure.
S-Band	RF frequency of approximately 2 GHz commonly used in manned space communications.



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13.0 Acronyms

ACRFG	Assembly and Contingency Radio Frequency Group
DC	direct current
EVA	Extravehicular Activity
GHz	Giga Hertz
GSFC	Goddard Space Flight Center
He	helium
ISS	International Space Station
JPL	Jet Propulsion Laboratory
MDA	MacDonald, Dettwiler and Associates Ltd.
N ₂	nitrogen
NASA	National Aeronautics and Space Administration
NESC	NASA Engineering and Safety Center
NRB	NESC Review Board
ORU	Orbital Replacement Unit
psia	pounds per square inch absolute
RF	radio frequency

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14.0 References

1. “ACRFG Reflected RF Power Anomaly, Second Draft,” MDA, May 5, 2006.
2. Dallaire, Jean, “ISS ACRFG Corona Test Description,” May 25, 2006.
3. Hunt, Corrie, “S-band RFG1 Lower Operational Pressure Limit Violation FIT (IFI 1678) Boeing C&T,” January 21, 2005.
4. “ISS ACRFG Reflected Power Anomaly Tx Bandpass Filter Corona Test Technical Report #RML-009-2006-110,” MDA, August 21, 2006.
5. Norris, Mike, “Performance Degradation of S-Band String 1 RFG,” EV16, May 25, 2006.
6. Woo, R., “Final Report on RF Voltage Breakdown in Coaxial Transmission Lines.” NASA Technical Report No. 32-1500, October 1, 1970.

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Appendix A. ITA/I Request Form (NESC-PL-06-22)

NASA Engineering and Safety Center Request Form		
Submit this ITA/I Request, with associated artifacts attached, to: nrbexecsec@nasa.gov , or to NRB Executive Secretary, M/S 105, NASA Langley Research Center, Hampton, VA 23681		
Section 1: NESC Review Board (NRB) Executive Secretary Record of Receipt		
Received (mm/dd/yyyy h:mm am/pm) 5/8/2006 8:40 AM	Status: New	Reference #: 06-028-E
Initiator Name: Penney Saunders	E-mail: penney.e.saunders@nasa.gov	Center: JSC
Phone: (281)-483-1485, Ext _____	Mail Stop: OD	
Short Title: ISS S-Band Corona Discharge Anomaly		
Description: Hi David, Here's the description of the support we need.		
<ul style="list-style-type: none"> •NESC consultation support in the area of high voltage corona in an RF system. Read and evaluate reports from the S-band RF Group ORU vendor, MDA, on the probability of corona occurring in the Assembly and Contingency RF Group (ACRFG) which is used by the ISS for command and control communications. Support near term technical discussions on the matter. •The ACRFG is nominally pressurized with H₂. One of the ISS ACRFGs has leaked down to a pressure of 1 psi. A recent problem with an increased reflected RF power signature in this unit has resulted in MDA re-analyzing the possibility of corona occurring at 1 psi or lower. Based on this analysis, MDA does not recommend power-on of the ACRFG. This ACRFG is usually powered off, since it is the back-up string. (The string that is nominally powered on is operating within specifications.) •We need immediate support since both strings are powered on for EVAs, dockings, and undockings. A Russian EVA is scheduled for June 1st. Since the station is unmanned during the EVAs, the flight rules require both strings to be powered on for command and control of the ISS in the event of a problem. I anticipate the first technical meeting to occur as soon as this Wednesday - maybe tomorrow. 		
I will forward the report from MDA in a separate e-mail (sorry to clog your e-mail) just in case you can start moving right away. Thank you for helping us out. Penny .		
Source (e.g. email, phone call, posted on web): Email		
Type of Request: Consultation		
Proposed Need Date:		
Date forwarded to Systems Engineering Office (SEO): (mm/dd/yyyy h:mm am/pm):		
Section 2: Systems Engineering Office Screening		
Section 2.1 Potential ITA/I Identification		



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Received by SEO: (mm/dd/yyyy h:mm am/pm): 5/8/2006 12:00 AM	
Potential ITA/I candidate? <input type="checkbox"/> Yes <input type="checkbox"/> No	
Assigned Initial Evaluator (IE): Bob Kichak	
Date assigned (mm/dd/yyyy): 5/9/2006	
Due date for ITA/I Screening (mm/dd/yyyy):	
Section 2.2 Non-ITA/I Action	
Requires additional NESC action (non-ITA/I)? <input type="checkbox"/> Yes <input type="checkbox"/> No	
If yes:	
Description of action:	
Actionee:	
Is follow-up required? <input type="checkbox"/> Yes <input type="checkbox"/> No If yes: Due Date:	
Follow-up status/date:	
If no:	
NESC Director Concurrence (signature):	
Request closure date:	
Section 3: Initial Evaluation	
Received by IE: (mm/dd/yyyy h:mm am/pm):	
Screening complete date:	
Valid ITA/I candidate? <input type="checkbox"/> Yes <input type="checkbox"/> No	
Initial Evaluation Report #: NESC-PN-	
Target NRB Review Date:	
Section 4: NRB Review and Disposition of NCE Response Report	
ITA/I Approved: <input type="checkbox"/> Yes <input type="checkbox"/> No	Date Approved: _____
ITA/I Lead: _____, Phone (____) _____ - _____, x _____	Priority: - Select -
Section 5: ITA/I Lead Planning, Conduct, and Reporting	
Plan Development Start Date:	
ITA/I Plan # NESC-PL-	
Plan Approval Date:	
ITA/I Start Date	Planned: _____ Actual: _____
ITA/I Completed Date:	
ITA/I Final Report #: NESC-PN-	
ITA/I Briefing Package #: NESC-PN-	
Follow-up Required? <input type="checkbox"/> Yes <input type="checkbox"/> No	
Section 6: Follow-up	
Date Findings Briefed to Customer:	
Follow-up Accepted: <input type="checkbox"/> Yes <input type="checkbox"/> No	
Follow-up Completed Date:	
Follow-up Report #: NESC-RP-	
Section 7: Disposition and Notification	
Notification type: - Select -	Details: _____
Date of Notification:	
Final Disposition: - Select -	
Rationale for Disposition:	
Close Out Review Date:	



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Form Approval and Document Revision History

Approved: _____ NESC Director	_____ Date
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Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	Principal Engineers Office	29 Jan 04

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Approval and Document Revision History

Approved:	Original signed on file	1-4-07
	_____ NESC Director	_____ Date

Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	NESC Discipline Expert's Office	

REPORT DOCUMENTATION PAGE

*Form Approved
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PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 01-01-2008		2. REPORT TYPE Technical Memorandum		3. DATES COVERED (From - To) May 2006- Dec 2006	
4. TITLE AND SUBTITLE International Space Station (ISS) S-Band Corona Discharge Anomaly Consultation				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Kichak, Robert A.; Leidecker, Henning; Battel, Steven; Ruitberg, Arthur; Sank, Victor.				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 510505.06.07.03.99	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Engineering and Safety Center Langley Research Center Hampton, VA 23681-2199				8. PERFORMING ORGANIZATION REPORT NUMBER L-19440 NESC-RP-06-115/06-028-E	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITOR'S ACRONYM(S) NASA	
				11. SPONSORING/MONITORING REPORT NUMBER NASA/TM-2008-215100	
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 32 Communications And Radar					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The Assembly and Contingency Radio Frequency Group (ACRFG) onboard the International Space Station (ISS) is used for command and control communications and transmits (45 dBm or 32 watts) and receives at S-band. The system is nominally pressurized with gaseous helium (He) and nitrogen (N2) at 8 pounds per square inch absolute (psia). MacDonald, Dettwiler and Associates Ltd. (MDA) was engaged to analyze the operational characteristics of this unit in an effort to determine if the anomalous behavior was a result of a corona event. Based on this analysis, MDA did not recommend continued use of this ACRFG. The NESC was requested to provide expert support in the area of high-voltage corona and multipactoring in an S-Band RF system and to assess the probability of corona occurring in the ACRFG during the planned EVA. The NESC recommended minimal continued use of S/N 002 ACRFG until a replacement unit can be installed. Following replacement, S/N 002 will be subjected to destructive failure analysis in an effort to determine the proximate and root cause(s) of the anomalous behavior.					
15. SUBJECT TERMS NESC, Contingency Radio Frequency Group (ACRFG), International Space Station (ISS), Extravehicular Activities (EVAs), Orbital Replacement Unit (ORU), String 1 RFG, MDA RF corona analysis, printed circuit boards (PCB), bandpass filter assembly, multipactoring					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
UU	UU	UU	UU	31	19b. TELEPHONE NUMBER (Include area code) (301) 621-0390